1-1-2016

Early Growth and Survival of Shumard Oak and Nuttall Oak Planting Stocks

Johnathan Reeves

Early growth and survival of Shumard oak and Nuttall oak planting stocks

By

Johnathan Reeves

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Forestry
in the Department of Forestry

Mississippi State, Mississippi

May 2016

Early growth and survival of Shumard oak and Nuttall oak planting stocks

By

Johnathan Reeves

Approved:

Andrew W. Ezell
(Major Professor/Graduate Coordinator)

John D. Hodges
(Committee Member)

Emily B. Schultz
(Committee Member)

Andrew B. Self
(Committee Member)

George M. Hopper
Dean
College of Forest Resources

Name: Johnathan Reeves

Date of Degree: May 6, 2016

Institution: Mississippi State University

Major Field: Forestry

Major Professor: Dr. Andrew W. Ezell

Title of Study: Early growth and survival of Shumard oak and Nuttall oak planting stocks

Pages in Study: 69

Candidate for Degree of Master of Science

Hurricane Katrina damaged 1.4 million hectares of forestland in Mississippi. Hardwood timber accounted for 40 percent of the damage. A cost-effective method of artificial regeneration is necessary to restore this resource. Bareroot, containerized, and EKOgrown® seedlings of *Quercus shumardii* and *Quercus nuttallii* were planted on two sites for evaluation of survival and growth. Survival was recorded monthly during the first growing season, and at the end of each growing season. Growth was measured at the end of each growing season. Survival was extremely low in 2014. Containerized seedlings suffered a total loss due to freezing at the nursery, and a large flood occurred on one site. After the two growing seasons monitored in this study, bareroot seedlings provided similar or greater growth, greater survival, and were remarkably cheaper than EKOgrown® seedlings. Consequently, bareroot seedlings are recommended as the most cost-effective method of artificial oak reforestation.

ACKNOWLEDGEMENTS

I want to thank Dr. Andrew Ezell for presenting me with the opportunity to extend my education at Mississippi State University, and reassuring me that we would get through it when everything that could go wrong did go wrong. I would like to express my gratitude to Drs. John Hodges, Emily Schultz, and Brady Self for serving on my committee and supplying me with access to their vast knowledge and skillsets. My appreciation also goes to my officemates Alec Conrad, Drew Dowdy, Taylor Hall, and Tyler Durbin for providing their time to help with the implementation of this research during some long weekends when I am sure they had better things to do. I am grateful for having the best landowners I could have imagined in Mr. Justin “Popeye” Odom and Mr. Frankie Welford, and for their generosity by letting me conduct this growth study on their properties. Special thanks go to the USDA Farm Service Agency for providing funding, which allowed this research to take place. Recognition also goes to the many guys and girls that gave up their weekends to help with the field work portion of this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Hurricane Katrina was the third deadliest, most costly, and most destructive natural disaster to impact the Unites States (U.S.) in recorded history. On August 29, 2005, Hurricane Katrina made contact with the Gulf Coast as a Category 3 hurricane with wind speeds averaging 177km per hour (Blake et al. 2011). The storm caused 1,800 deaths and more than 100 billion dollars in damages to the U.S. Gulf Coast, mostly in Louisiana and Mississippi (Hurricane Katrina 2014).

Mississippi suffered the most timber damage. As the storm moved northward through the state, 1.4 million hectares of forestland were damaged (USDA 2005). Within that area, 12 million cubic meters of the damaged timber was hardwood (Prestemon and Holmes 2010). As salvage timber flooded the market, many landowners gained no revenue for their downed timber, and those who were able to harvest received only a small percentage of what their timber was previously worth. Many landowners sought alternative land use options that were more attractive than hardwood reforestation.

Rotation lengths of oak species are 50 years or more, and this can affect willingness to invest capital into producing an oak stand. There is a chance that another disastrous event could occur in that period, and some landowners are not willing to risk losing their money and product again. In addition, the average adult's lifespan may not be sufficient to complete the long length of the rotation. Unless landowners wish to use a forest for some alternative to producing timber (aesthetics, legacy, wildlife habitat, etc.), it is not likely that they will choose oak reforestation as their optimal land use.

Oak seedlings are most often established through natural regeneration. Substantial planning is required to regenerate bottomland oaks in this manner. Abundance of acorn crop, quantity of advanced regeneration, and ability to enter the stand in a timely manner are all obstacles to natural regeneration (Larsen and Johnson 1998). In the case of a natural disaster, the amount of mature trees remaining may not be sufficient to produce enough acorns for establishment thereby eliminating natural regeneration as an option. Artificial regeneration must therefore be used in such situations, and without revenue from the previous stand, many landowners cannot afford to restore their hardwood forest without the aid of cost-share programs.

Seedling survival has the largest influence on establishing any stand, and this is especially true with oaks. Planting oak seedlings is expensive and the cost must be carried for many years by the landowner. Cultural treatments such as using high quality seedlings, proper planting techniques, and competition control improve survival, and thus benefit the landowner and potential for future production (Self et al. 2011). It is important that a cost-effective method for artificially regenerating oaks be documented to provide information to landowners impacted by natural disasters such as Hurricane Katrina.

The first objective of this study was to evaluate the survival of three different planting stocks of Shumard oak (*Quercus shumardii)* and Nuttall oak (*Quercus nuttallii*) seedlings. The second objective was to determine the cause of mortality associated with seedling loss and quantify the results for each cause. The third objective was to evaluate the average height and groundline diameter (GLD) growth of each species/planting stock combination. The final objective was to use this information for comparing both species and planting stocks to provide performance results for landowner use. All objectives were to be satisfied from data collected over the first two years following planting.

CHAPTER II

LITERATURE REVIEW

Hurricane Katrina

Prestemon and Holmes (2010) estimated 29 million cubic meters of timber was downed by Hurricane Katrina in Mississippi alone. Mississippi Department of Agriculture and Commerce (2014) listed agriculture as the leading industry in Mississippi employing 29 percent of the workforce, and ranked forestry as the second highest agricultural commodity produced in the state. Sixty-three percent of the state is forested, and 54 percent of those forests are hardwoods (Oswalt 2015). The amount of timber damage caused by Hurricane Katrina was especially devastating considering forestry is such a large part of the state's industry. Restoring forest resources that have been lost from this natural disaster is crucial.

Restoration

Forest restoration is the act of returning the forest to the same conditions as some period in the past (Haynes 2004). It is important to define that period, the conditions present at that time, and choose an achievable goal. Many landscapes have changed drastically from the conditions that existed before Hurricane Katrina. Hardwood restoration had been a concern for many years prior to Hurricane Katrina, but after the storm, many additional hardwood stands were lost. Furthermore, some previous restoration efforts were once again damaged. Dey et al. (2006) discussed that walking away from disturbed lands results in forests that are dominated by pioneer species. Some of the main hardwood species occurring in the southeastern U.S. that were classified as pioneer by Burns and Honkala (1990) are maples (*Acer* spp.), sweetgum (*Liquidambar styraciflua*), winged sumac (*Rhus copallinum*), American sycamore (*Platanus occidentalis*), eastern cottonwood (*Populus deltoides*), and black willow (*Salix nigra*). Pioneer species are not necessarily undesirable, but typically are not considered as valuable as oaks economically, aesthetically, or biologically. Hanberry et al. (2012) addressed the concern that restoration efforts should be focused on economically and commercially valuable oaks rather than disturbance-sensitive species.

Incentives

Timber production for income and lumber products is valued in the United States; alternatively, wildlife habitat, aesthetics, and carbon sequestration are also recognized. Therefore, incentive programs have been established to provide funds to help landowners with restoration efforts. The Food Security Act of 1985 commonly referred to as the "Farm Bill" introduced land conservation programs to discourage draining wetlands and using highly erodible land for farming practices (Food Security Act 1985). Some Farm Bill programs that have established bottomland hardwoods are Wetlands Reserve Program (WRP), Wildlife Habitat Incentives Program (WHIP), and Conservation Reserve Program's (CRP) Bottomland Hardwood Initiative (BHI). The Food Security Act of 1985 was most recently amended by the Agriculture Act of 2014 replacing WRP with Wetland Reserve Enhancement Partnership (WREP) and combining WHIP within Environmental Quality Incentive Program (EQIP) (NRCS 2015). WRP has provided incentives to landowners for restoring wetland forest resulting in over 150,000 hectares of bottomland forest being planted prior to Hurricane Katrina (Haynes 2004), and Rewa (2000) estimated 50 percent of all lands enrolled in WRP consist of bottomland hardwood forest. Tree planting data from NRCS (2015) stated that WHIP planted over 200,000 hectares of forest between 2009 and 2014. The 2014 Farm Bill Field Guide indicated that CRP has planted 18,200 hectares of bottomland hardwoods since 2005 (North American Bird Conservation Initiative 2015). Table 2.1 compares current information from WREP (formerly WRP), WHIP, and CRP (NRCS 2015). These programs should be utilized to offset high establishment costs, which usually discourage landowners from planting oaks or other hardwoods.

Table 2.1 2015 cost-share programs available for bottomland hardwood establishment.

Program	WREP	WHIP	CRP (BHI)
Purpose	Restore, protect, and enhance wetlands.	Restoration, development, protection, and improvement of wildlife habitat.	Restore bottomland hardwoods within floodplains.
Contract Length	Permanent, 30 yr, Term	Not to exceed 10 yr	10-15 yr
Payment	50-100% easement value 50-100% restoration cost	75% of cost 100% of forgone income	$150/ac sign-up 120% soil productivity 90% establishment

Regeneration

Two basic regeneration options exist when establishing a stand of trees: natural or artificial. Smith (1962) described natural regeneration as developing from a source on the site, while artificial regeneration is planted with some form of human interaction from a source that is brought to the site. He also explained that the procedure of regeneration is named in accordance with the harvest technique and termed a silvicultural system. Five basic silvicultural systems exist: clearcut, seed-tree, shelterwood, selection, and coppice. What is referred to as a clearcut is actually a 1-cut shelterwood because advanced regeneration must be present to be successful. Meadows and Stanturf (1997) explained that clearcut (1-cut shelterwood) and shelterwood methods are the two silvicultural systems used for oak reproduction, and that some coppice may occur but is not the main method of reproduction. The seed-tree method favors light seeded shade intolerant species, and is not applicable to heavy seeded species (Toliver and Jackson 1989). Neither single tree nor group selection is sufficient to produce light needed for shade intolerant species to reach the advance reproduction stage (Clatterbuck and Meadows 1992) when using a definition of group selection to be an area less than 0.2 hectares, and areas larger than 0.2 hectares to be called a patch cut or patch clearcut.

Natural Regeneration

Natural regeneration requires extensive planning and management of the existing stand to implement correctly. Some of the main steps in natural regeneration of oaks include evaluating the site to determine if regeneration potential exists, matching correct species to the site, monitoring acorn crop abundance, creating conditions for adequate light, acquiring sufficient advance regeneration, and choosing a harvest method (Clatterbuck and Meadows 1992). If any of those steps are implemented incorrectly or are not taken, natural regeneration will likely be insufficient to produce the desired stand. Clearcut (1-cut shelterwood) and shelterwood methods can be used for natural regeneration. It should be noted however, that natural regeneration of oaks using the clearcut method would require adequate advance regeneration and/or a bumper acorn crop to be successful (Johnson 1981, Stanturf and Meadows 1994). The shelterwood method is the most flexible and most reliable method to naturally regenerate oaks (Johnson et al. 2009). “Natural regeneration of oaks is often the best alternative for forest stands when sufficient time is available to supply silvicultural treatments that are required for successful regeneration; however, there are some situations in which it is not practical or possible to rely on natural regeneration alone” (Dey et al. 2008, p. 77). Situations when a seed source might not be available are after a natural disaster or when afforesting former agricultural areas; therefore, some form of artificial regeneration must be used.

Artificial Regeneration

Artificial regeneration is normally used after a clearcut when sufficient regeneration does not exist or to afforest retired agricultural fields or pastures; it could also be used if the shelterwood method fails or collectively with other methods (Johnson et al. 2009). A catastrophic event is essentially treated as clearcut without sufficient regeneration. Artificial regeneration of oaks is accomplished by one or any combination of three main categories: direct seeding, planting bareroot seedlings, or planting containerized seedlings.

Direct seeding

Direct seeding involves planting seeds of a desired species that are brought to the site instead of being dispersed by trees on site (Ezell 2014). The results of using direct seeding have been inconsistent, especially when using commercial planting crews. One cause of inconsistency may be that germination rates of commercial planting average around 35 percent compared with up to 80 percent in research (Kennedy 1992). Bullard et al. (1992) reported the advantages of direct seeding include more flexible planting season, faster planting time, and lower planting cost, but the disadvantages are decreased establishment success, increased site preparation, and reduced stocking caused by animal destruction. Dey et al. (2008) listed multiple accounts of research supporting animal predation, mostly rodents, as the main cause of failure when using direct seeding to establish oaks.

Bareroot seedlings

Bareroot seedlings have their roots exposed when planted on the permanent site, and are described with numbers corresponding to age and transplanting in the nursery (Jacobs 2003). The first number signifies the number of growing seasons the seedling remained in the original seedbed, while the second number indicates how many growing seasons, if any, the seedling was transplanted into a different bed at the nursery (Dumroese and Owston 2003). Bareroot seedlings cost the least, and are the most planted stocktype in the eastern United States (Dey et al. 2008). The most common seedling planted in the South is the 1-0 bareroot (Schoenholtz et al. 2005). High-quality bareroot seedlings will ordinarily result in the most economical method of consistently establishing oaks as long as proper planting techniques and proper handling techniques are applied (Allen and Kennedy 1989). Ezell and Hodges (2002) demonstrated that controlling herbaceous competition can significantly improve bareroot seedling survival and likelihood of successful stand establishment if good seedlings and proper planting are employed.

Containerized seedlings

Containerized seedlings are produced in many different sizes and ages by nurseries. The medium in which the seedling is planted will accompany the root system to the permanent site and help protect against planting shock (Allen et al. 2001). Over the years, containerized seedling performance has fluctuated below (Kormanik et al. 1976) or above (Humphrey et al. 1993) bareroot seedlings. Survival of containerized seedlings and bareroot seedlings has been similar in recent research (Alkire 2011), although containerized seedlings may grow taller than bareroot seedlings during their first year (Burkett and Williams 1998, Williams and Stroupe 2002). Burkett et al. (2005) followed a planting through later years and discovered bareroot seedlings' growth equaled that of containerized seedlings in year two and overtook them by year three with similar or greater survival. Containerized seedlings offer the advantage of an extended planting season (Williams and Craft 1998), but cost more than bareroot seedlings. They can be a useful planting option in drought prone areas or as a later planting option in areas that stay inundated during normal planting season (Humphrey et al. 1993).

Large potted seedlings

Within the last couple of decades, nurseries have started producing larger potted seedlings on a commercial scale by either the tradename RPM® (root production method) seedlings or the tradename EKOgrown® seedlings (EKO used as working abbreviation). RPM® seedlings are sold in 11.4L or 19L pot sizes, with a few specialty trees in pots as large as 58L (Forest Keeling Nursery 2014). EKOgrown® seedlings are available in 3.8L and 11.4L pot sizes (EKOgrown® 2015).The use of EKOgrown® seedlings has increased because the trees are reported to be more resistant to inundation, competition, and herbivory. Many of these seedlings can measure from 1.5m to 2.0m tall after one growing season in the nursery depending on species (Haynes 2004, Conrad 2013). One advantage of using EKOgrown® seedlings may be an earlier payoff for wildlife contributions. Dey et al. (2006) observed acorn production on a small percentage of swamp white oak (*Quercus bicolor*) RPM® seedlings one year after planting. There has been an increased interest to determine the economic and biological potential for planting these more costly seedlings, but more evaluation is needed.

Competition Control

Mechanical

Mechanical competition control such as mowing and disking can successfully remove competition, but last for very short periods of time and have to be repeated frequently (Seifert et al. 2007). Mechanical site preparation techniques of combination plowing and bedding have shown beneficial to seedling growth (Self et al. 2012). They also found in the same study that subsoiling had no effect on growth, while in another study by Self et al. (2010) subsoiling had a large impact on seedling growth. The difference in response was attributed to site and environmental conditions prior to site preparation and in the subsequent growing seasons. Even though they may improve performance, mechanical site preparation techniques are performed in fall and offer no real competition control during the growing season. Typically, mechanical competition control is not cost effective for most forest operations (Bried and Gifford 2010).

Chemical

Herbicide application is often the most efficient method of weed control, but a land manager must consider the species to be controlled and crop trees (Seifert et al. 2007). Chemical site preparation should be used only if species are present that will not be controlled by a post-planting herbaceous weed control (HWC) application, because it will not provide enough residual action to control growing season herbaceous competition (Self et al. 2013). Gardiner et al. (2007) found that two years after outplanting, competition from herbaceous vegetation increased Nuttall oak seedling mortality by 51 percent, reduced height growth by 61 percent, and reduced diameter growth by 61 percent. First year application of HWC will improve survival of oak seedlings (Ezell et al. 2007), which is the main concern during the first few years of establishment.

Species

Nuttall oak

Nuttall oak grows in poorly drained soils of river bottom flats (Burns and Honkala 1990). Hodges et al. (2008) reported the range of Nuttall oak from Alabama west to Texas northeast to Illinois and Kentucky following the lower Mississippi River valley. They also stated Nuttall oak may reach a height of 30m at maturity; is intolerant to shade, drought, and fire; and has low anaerobic tolerance. Day et al. (1998) and Mercker et al. (2011) demonstrated greater survival and growth rates of Nuttall oak on sites with poor drainage or periodic flooding when compared to other red oaks. Nuttall oak is also an important part of wildlife habitat and source of food in these areas. Neotropical songbirds prefer nesting and are more likely to nest successfully in mature Nuttall oak trees, which is possibly linked with snakes being incapable of climbing the tree and depredating nest (Mullin and Cooper 2002). Bonner (1974) determined that acorns from Nuttall oaks have 15 to 30 percent higher caloric content per gram than other oak species occurring in the same area, with the exception of pin oak (*Quercus palustris*) where ranges overlap.

Shumard oak

Shumard oak grows best in moist well-drained soils on ridges and terraces of river bottoms, but can also grow on upland and dry sites (Burns and Honkala 1990). Shumard oak has a moderate growth rate, may approach a height of 35m at maturity, is intolerant of shade and anaerobic conditions, has low fire tolerance, and has a high drought tolerance (Hodges et al. 2008). They also indicate that the upper limit of Shumard oak extends from Nebraska to Michigan to Pennsylvania and it grows everywhere south of that. In addition to having a large geographic range, it may have the capability to be grown in areas that will not support other oak species. Shumard oak can grow in soils with high pH levels that are unsuitable for other oaks (Kennedy and Krinard 1985). On the other hand, Shumard oak is highly susceptible to the oak wilt fungus and rapidly declines once infected (Wilson 2005). In areas where oak wilt is present, other species should probably be considered over Shumard oak.

Mortality

Freezing

Seedling shoots are more freeze tolerant than their roots, and young roots are more sensitive than older ones (Bigras and Dumais 2005). Bareroot seedlings rarely experience freeze damage because their roots are protected by the soil, but containerized seedlings are susceptible prior to planting due to lack of insulation being provided by the small container. Root freezing is the most common overwinter injury to containerized seedlings, and it often goes unnoticed until after outplanting because symptoms are not evident (Landis et al. 2010). If only the buds survive freezing, they will die shortly after breaking dormancy because nutrients cannot be transported from damaged roots or shoots (Barney 1991). Barney (1991) also stated that plants might look and/or grow normal into June or July before suddenly dying. Improper storage can lead to bareroot seedlings' roots freezing, but this is the handlers fault and can be easily avoided. Even though seedlings freezing is rarely a problem, it can decimate an entire planting.

Flooding

Bottomland hardwoods are adapted to withstand flooding during winter while trees are dormant. King and Fredrickson (1998) listed both Nuttall oak and Shumard oak as being able to withstand dormant season floods for a period of one to three months. Flooding during the growing season may cause various degrees of damage to different species, and newly planted seedlings are more susceptible to flood damage than established trees (Smith 1962). Nuttall oaks have been shown to decrease gas exchange when flooded and rapidly recover once water recedes (Anderson and Pezeshki 1999), which attributes to its flood tolerance. McLeod et al. (1999) showed that Shumard oak and post oak (*Quercus stellata*) are intolerant of flooding with no Shumard oak and only 11 percent of post oak surviving five years after planting on a low bottomland site. Growing season floods rarely occur in consecutive years on hardwood bottomland sites, which allows for naturally regenerating seedlings to establish in the next year if present year seedlings are killed. Planting seedlings is a large investment, and when a growing season flood occurs, seedlings may be lost without a way to be naturally replaced. Growing season floods on bottomland hardwood sites are unpredictable in many areas and can be very destructive to regeneration efforts.

Beaver damage

There are many documented cases of herbivory by large mammals such as whitetail deer (*Odocoileus virginianus*) to oak seedlings (Ruzicka et al. 2007, Marquis et al. 1976). Smaller mammals can be just as destructive to seedlings, especially under certain conditions (Self 2011 and Krinard and Johnson 1981). If flooding occurs, American beaver (*Castor canadensis*) can cause a restoration project to fail in multiple ways. They dam drainages causing water impoundment, which causes floodwater to remain on the site and kill trees (King and Fredrickson 1998). Beavers may also cut woody stems to use for building material when constructing dams (Baker and Hill 2003). The largest afforestation concern relating to beaver destruction may be consumption of seedlings for food. Krinard and Johnson (1981) observed beavers pulling newly planted seedlings from the ground and consuming the root system. There is more than one reason this type of damage is so destructive. Small oaks that are cut off above ground with the root system intact will normally resprout (Johnson 1992), but when the roots are consumed, resprout potential is lost. Seedlings are also planted in straight rows, so that once a beaver finds that food source they can stay in the water, follow the rows, and destroy the entire stand row by row.

Conclusion

Many aspects must be taken into account when considering restoration. First, a detailed description of desired conditions to be restored must be stated clearly and effectively. Economic and ecologic factors should be considered when determining planting sites, species, stock types, and competition control. The “do nothing” approach must always be considered and could be the best option to meet certain goals. Finally, the most important consideration is landowner’s objectives and budget constraints. Even with the best plan, not all circumstances can be foreseen. Failure is always a possibility, and land managers should take all reasonable measures to prevent that outcome.

CHAPTER III

MATERIALS AND METHODS

Site Description

Two properties in south Mississippi, separated by 80 kilometers latitudinally, were used in this study. Both sites were bottomland sites with sandy soils, and held water during wet seasons. The average annual rainfall for these areas is 168 centimeters, and average annual temperature is 19º C (U.S. climate data 2015).

The Odom Site was located in northeastern Perry County, MS, adjacent to the county line and DeSoto National Forest. The coordinates, expressed in decimal degrees (DD), at the center of this site were 31.43º N and 88.91º W. This site had previously been used as a pasture for cattle (*Bos taurus*) grazing. Savannah fine sandy loam and Stough fine sandy loam soil types were present on the site (Web Soil Survey 2015). Soil pH ranged from 4.5 to 4.7. Levels of soil macronutrients were all above average except for a low potassium level. Baker and Broadfoot (1979) site index for Nuttall oak was 82ft (25m) and Shumard oak was 78ft (23.8m) at 50 years. Site preparation included mowing and subsoiling to remove the extensive herbaceous layer and break the compaction resulting from livestock activity.

Previous vegetation cover on the Odom Site was mostly grasses with some tree seedlings, vines, and broadleaf weeds dispersed throughout. Species that occurred included: broomsedge bluestem (*Andropogon virginicus*), dogfennel (*Eupatorium* *capillifolium*), boneset (*Eupatorium perfoliatum*), bullgrasses (*Muhlenbergia* spp.), panicgrasses (*Panicum* spp.), *Paspalum* spp. (hereafter referred to as paspalum), water oak (*Quercus nigra*), willow oak (*Quercus phellos*), *Rhexia* spp. (hereafter referred to as rhexia), *Rubus* spp. (hereafter referred to as rubus), black willow (*Salix nigra*), goldenrod (*Solidago* spp.), smutgrass (*Sporobolus indicus*), Chinese tallow tree (*Triadica sebifera*), and signalgrasses (*Urochloa* spp.).

The Welford Site was located in southeastern George County, MS, approximately 10 miles southeast of Lucedale, MS, and two miles west of the Alabama state line. It bordered the Escatawpa River, which periodically floods during wet years. The coordinates, expressed in DD, for the center of this site were 30.82º N and 88.45º W. It had previously been a pine/mixed hardwood site, and the area remained covered with debris from Hurricane Katrina. Soil types Harleston fine sandy loam and Lenoir silt loam occurred on this site (Web Soil Survey 2015). Soil pH ranged from 4.3 to 4.8. Baker and Broadfoot (1979) site index for Nuttall oak and Shumard oak was 81ft (24.7m) at 50 years. Levels of soil macronutrients at this site were all below average. Site preparation consisted of using a bulldozer to clear debris from the site.

Previous vegetation cover on the Welford Site was mostly pine and mixed hardwoods with vines, broadleaf weeds, and grasses in openings between trees. Species that covered the site included: boxelder (*Acer negundo*), broomsedge bluestem, wiregrasses (*Aristida* spp.), hickories (*Carya* spp.), yellow nutsedge (*Cyperus esculentus*), dogfennel, boneset, green ash (*Fraxinus pennsylvanica*), deciduous holly (*Ilex decidua*), sweetbay magniolia (*Magnolia virginiana*), blackgum (*Nyssa sylvatica*), panicgrasses, slash pine (*Pinus elliottii*), sycamore (*Platanus occidentalis*), oaks, rubus, goldenrod, bur-reed (*Sparganium americanum*), Chinese tallow tree, and signalgrasses.

Seedlings

Shumard oak and Nuttall oak were evaluated in this study. Three planting stocks of each species were used including high-quality 1-0 bareroot, 240mL conventional containerized, and 3.8L potted seedlings. Rayonier nursery in Alberta, AL, produced the bareroot stock, conventional containerized stock was produced by Mossy Oak Native Nurseries in Osborn, MS, and EKOgrown® seedlings were grown by Resource Environmental Solutions (RES) native tree and coastal marsh grass nursery in Montegut, LA. Mississippi State University (MSU) personnel planted both the bareroot and conventional containerized planting stocks in February 2014. The EKOgrown® seedlings were planted in April 2014 by a commercial planting crew, with a MSU researcher on site for supervision.

Experimental Design

A randomized complete block design was utilized with three blocks per site represented by roman numerals I, II, and III. Each block had six treatments (species/planting stock combination) with 100 trees per treatment. The six treatments were: 1) bareroot Nuttall oak (NUO), 2) bareroot Shumard oak (SHO), 3) conventional containerized NUO, 4) conventional containerized SHO, 5) EKOgrown® NUO, and 6) EKOgrown® SHO. The treatments were differentiated in the field by a colored pin flag at each tree that corresponded to a treatment. Re-bar with flagging and aluminum tags was used to mark each row. Replicate letter, treatment number, planting stock, species, row number, and pin flag color were inscribed on each tag.

Plot Establishment

Trees were planted on the Odom Site using a 3m x 3m spacing with 100 trees per treatment. Blocks I, II, and three treatments of III had 25-tree rows with an east/west orientation parallel to each other across the site. The other three treatments of block III had 50-tree rows (after tree number 25 another re-bar was placed and 25 more trees were added). The 50-tree rows were positioned perpendicular to the other rows on the site in order to remain within space constraints (Figure 3.1).

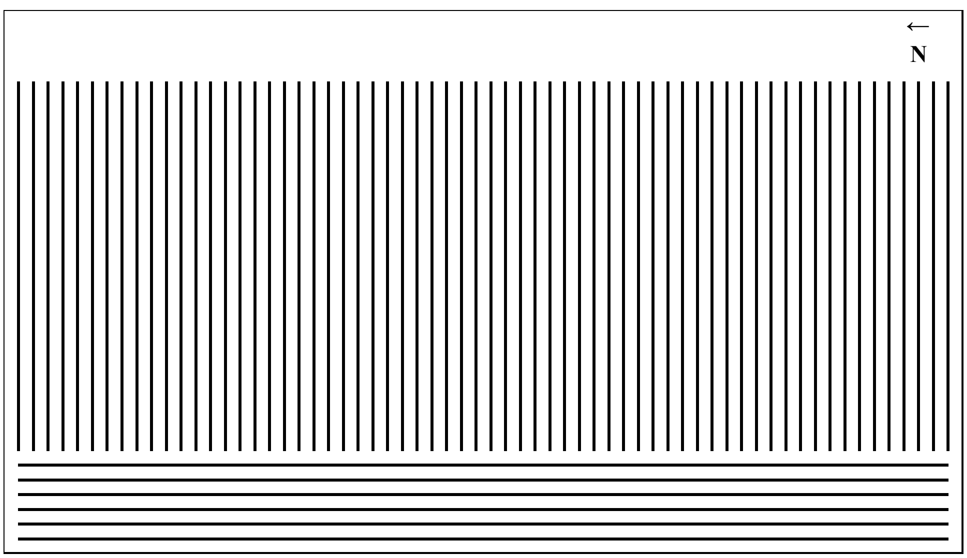

Figure 3.1 Row Distribution and Direction on Odom Site in Perry County, MS.

Planting at the Welford Site utilized a 2.4m x 2.4m spacing due to available space constraints. However, within duration of this research, root systems are not anticipated to expand to the point of competing with neighbor seedlings. Given the configuration of the boundaries of the site, blocks I and II utilized four 25-tree rows per treatment, while block III had two 33-tree rows and one 34-tree row per treatment to remain within available space east to west (Figure 3.2).

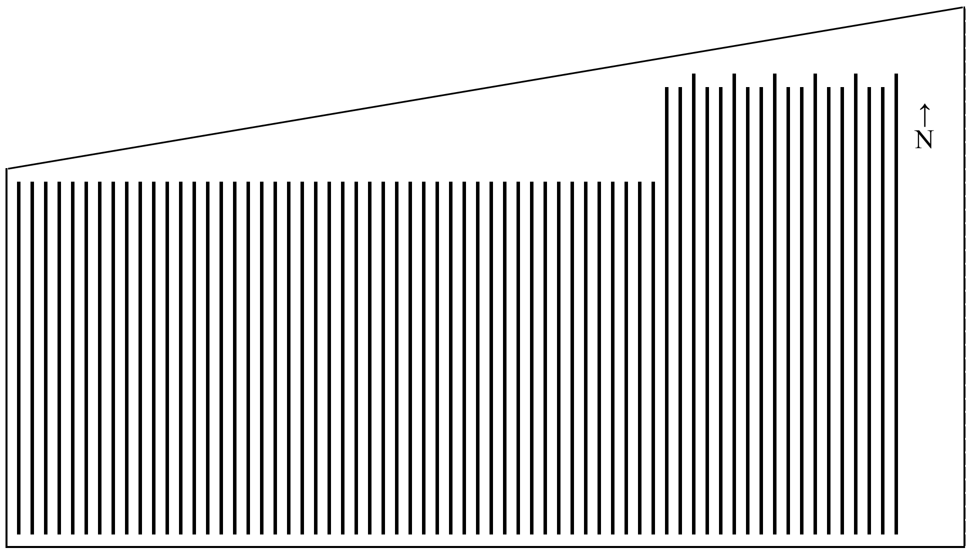

Figure 3.2 Row Distribution and Direction on Welford Site in George County, MS.

Herbaceous Weed Control

Herbaceous weed control (HWC) was applied to the bareroot and conventional containerized seedling in March 2014 and 2015 to suppress competing herbaceous vegetation, thereby increasing the seedlings chances for survival and growth. HWC is a widely accepted practice for establishing bareroot and conventional containerized hardwood seedlings in the South. Oust® XP was applied as a 1.5m swath banded application over rows of these two planting stocks at a rate of 140g per treated hectare (ha). A Solo® 425 backpack sprayer equipped with a TeeJet® XR8003 nozzle was used for application using 93L total spray volume per treated ha. No HWC treatment was applied to EKOgrown® seedlings, as they are promoted as being able to out-compete the vegetation surrounding them.

Data Collection

Survival

Survival counts were conducted monthly during the first growing season, and at the end of the first and second growing seasons. Every planted tree was evaluated during these counts. Trees were recorded as dead only when all green tissue was absent from leaves and cambium. Field data were entered into Microsoft® Excel® for calculations and record keeping.

Precipitation

Precipitation was measured at both sites using a Rainwise® 111 tipping bucket gauge connected to a Hobo® UA-003-64 pendant event data logger. The tipping bucket gauge measured precipitation 2.5mm at a time and stored the event on the data logger with a date and time stamp. A Hobo® U-DTW-1 waterproof shuttle was used to extract and transport the information stored on the data logger. At the laboratory, the shuttle was connected with HOBOware pro software on a computer and a readout was displayed with times, dates, and measurements. Precipitation data readouts were recorded each month with survival checks.

Measurements

Groundline diameter (GLD) and total height measurements were recorded initially on April 26-27, 2014. Initial measurements were recorded after at least two rain events following planting to allow soil to settle around the base of the seedlings.

Measurements were repeated at the end of the first growing season on November 8-9, 2014, and at the end of the second growing season on October 3-4, 2015. Dieback, herbivory, and resprouts were recorded for use in data analysis.

Groundline diameter

Mitutoyo® digital calipers were used to measure GLD. Calipers were held level at a point just above the ground surface. Measurements were recorded in tenths of a millimeter, and calibration was checked after each measurement.

Height of seedlings

Picket ASE-48 aluminum straight edges (120cm) were used to measure the total height of the seedlings. Total height was measured from ground to the terminal bud. If the seedling was taller than the straight edge, the seedling was marked at 100cm, then measured from the mark with the second measurement added to 100cm. Total height measurements were recorded to the closest centimeter.

Statistical Analysis

SAS® 9.4 software was used to perform statistical analyses on data collected. PROC GLM was used to perform an analysis of variance to determine significance of average GLD growth, average height growth, and survival of seedlings for each main effect and possible interactions. Significant differences were detected, so a multiple comparison procedure was used to determine significance using the LSMEANS statement with the Tukey-Kramer method. PROC GLM, LSMEANS, and Tukey-Kramer were implemented because sample populations were not equal due to mortality.

Additionally, the Tukey-Kramer method was used over other methods because it accounts for all pairwise interactions. An alpha level of 0.05 was used in all testing.

CHAPTER IV

RESULTS

Analysis of variance

Analysis of variance (ANOVA) was used to determine if any statistical similarities could be confirmed for the main effects and interactions of species, site, and/or planting stock on average groundline diameter (GLD) growth (Table 4.1), average height growth (Table 4.2), and survival (Table 4.3) of seedlings used in this research. Results from each variable are explained subsequently within the appropriate section for each main effect or interaction. Conventional containerized planting stock is excluded from all analyses due to total loss (explained in the survival section).

Table 4.1 ANOVA results for average groundline diameter growth by year and overall for the 2013 Hurricane Katrina reforestation project.

		Growing Season					
		2014		2015		Overall	
Source	DF	F	P > F	F	P > F	F	P > F
A) Species	1	161.55	<0.0001	92.23	<0.0001	105.82	<0.0001
B) Stock	1	30.70	<0.0001	2.93	0.0871	2.29	0.1307
C) Site	1	21.01	<0.0001	45.05	<0.0001	28.10	<0.0001
A * B	1	33.84	<0.0001	12.96	0.0003	0.11	0.7404
B * C	1	0.62	0.4321	9.10	0.0026	6.18	0.0130
A * C	1	0.01	0.9281	34.42	<0.0001	10.53	0.0012
A * B * C	1	5.37	0.0207	0.80	0.3720	2.16	0.1420

Table 4.2 ANOVA results for average height growth by year and overall for the 2013 Hurricane Katrina reforestation project.

		Growing Season					
		2014		2015		Overall	
Source	DF	F	P > F	F	P > F	F	P > F
A) Species	1	26.83	<0.0001	14.93	0.0001	27.30	<0.0001
B) Stock	1	0.39	0.5301	24.83	<0.0001	18.76	<0.0001
C) Site	1	9.99	0.0016	37.32	<0.0001	61.69	<0.0001
A * B	1	0.33	0.5628	20.74	<0.0001	22.17	<0.0001
B * C	1	0.56	0.4551	19.00	<0.0001	9.72	0.0019
A * C	1	1.59	0.2070	3.13	0.0769	3.29	0.0698
A * B * C	1	0.11	0.7393	12.05	0.0005	8.24	0.0042

Table 4.3 ANOVA results for survival by year and overall for the 2013 Hurricane Katrina reforestation project.

		Growing Season			
		2014		2015	
Source	DF	F	P > F	F	P > F
A) Species	1	248.41	<0.0001	482.66	<0.0001
B) Stock	1	32.38	<0.0001	24.58	<0.0001
C) Site	1	457.98	<0.0001	355.65	<0.0001
A * B	1	56.29	<0.0001	21.77	<0.0001
B * C	1	30.12	<0.0001	4.57	0.0326
A * C	1	0.21	0.6505	0.01	0.9226
A * B * C	1	142.42	<0.0001	78.25	<0.0001

ANOVA testing only reports if significant differences are or are not detected within the variables set forth. Since differences were detected, further investigation was necessary. A Tukey-Kramer multiple comparisons procedure (MCP) was performed on data to discover which groups of interactions were significant within species, planting stocks, and sites.

Survival and precipitation during first growing season

Survival during the first growing season was unexpectedly low for this project. Seedlings were planted during winter while dormant, and appeared to be normal with no signs of damage. Survival was counted and precipitation data were retrieved the last week of each month following planting during the first growing season. No monthly evaluations were completed after the first growing season.

One complete planting stock (conventional containerized) was discovered to be dead during the first month's survival count (April 2014). Nursery inquiries revealed that large quantities of containerized seedlings had dyed that year. Investigation into the matter determined the most probable cause was freeze damage at the nursery. January 2014, was unusually cold for the area, and containerized seedlings overwinter outdoors. Conventional containerized seedlings will be excluded from all data presentation and analyses due to complete failure of the planting stock.

Monthly precipitation during the first growing season

Precipitation during the 2014 growing season was similar across sites and to monthly averages in the area (U.S. Climate Data 2015), with the exception of April rainfall at the Welford Site (49cm) (Table 4.4). On April 29-30, 2014, the Welford Site received an abnormally large amount of rain (25.1cm), equaling more than the remainder of the month combined (23.9cm). April was already a wet spring month with 14 percent of the average annual rainfall occurring not including the major rain event. The excessive rainfall caused a major rise of the nearby Escatawpa River from an average depth of 1m to over 6m inundating the study area and submerging seedlings. Flooding impacts on seedlings are discussed within associated growth and survival sections.

Table 4.4 Monthly precipitation at each site during the first growing season of the 2013 Hurricane Katrina reforestation project.

Site	April	May	June	July	August	September	October
	Centimeters						
Odom	20.8	20.9	15.4	9.2	5.8	8.6	8.5
Welford	49.0*	29.7	11.9	7.4	5.5	9.3	8.7

*25.1cm occurred on April 29 and 30.

Monthly survival during first growing season

Survival at the Welford Site suffered a rapid decline between April and May of the first growing season for all treatments (19 – 56 percent) (Table 4.5), coinciding with flooding that occurred on the site. Inundation is credited with the mortality of 29 percent of seedlings on the Welford Site with the majority being Shumard oak (Table 4.6). In conjunction with the flood, American beavers destroyed 22 percent of the seedlings at the Welford Site. Damage was identified as pulled up bareroot seedlings with shoots clipped and consumed roots. They also pulled up and clipped the shoots of EKOgrown® seedlings, but no root consumption could be confirmed, as the root balls remained intact on-site. Damage was linear in nature, indicating that beavers progressed along a planted row following the rising or falling water line, which is similar to damage reported by Krinard and Johnson (1981). Survival on the Welford Site remained relatively constant after loss from flood related damage in 2014.

The Odom Site had greater survival throughout the first growing season compared to the Welford Site. Both Nuttall oak planting stocks at the Odom Site had greater than 90 percent survival at the end of the first growing season (Table 4.5). Survival of EKO Shumard oak seedlings steadily declined throughout the growing season averaging 4.5 percent loss per month at the Odom Site. Survival of bareroot Shumard oak seedlings at the Odom Site declined 15 percent between April and June, possibly caused by poor site drainage and heavy precipitation. Hook (1984) stated that Shumard oak seedlings exhibit poor survival and height growth in saturated soils. Survival of bareroot Shumard oak seedlings at the Odom Site declined another 16 percent between August and October, presumably caused by the small amount of precipitation in August (Table 4.4) and increased competition on the site. Establishment of Shumard oak seedlings is highly reliant on adequate light and moisture that can be obstructed by competing vegetation (Burns and Honkala 1990). Gazal and Kubiske (2004) found Shumard oak seedlings to maintain leaf gas exchange rates regardless of atmospheric conditions causing poor performance in dry conditions. Both of these spikes in mortality may be explained by early growing season soil saturation impeding root growth, therefore affecting the roots' ability to compete for and provide adequate moisture to seedling during the drier period.

Table 4.5 Monthly survival per treatment by site during the first growing season of the 2013 Hurricane Katrina reforestation project.

Site	Treatment	Month						
		Apr	May	Jun	Jul	Aug	Sept	Oct
		Percent						
Odom	Bareroot Nuttall oak	100a*	100a	100a	100a	100a	100a	98a
	Bareroot Shumard oak	100a	94ab	85abc	83abc	82abc	75bcd	66cde
	EKO Nuttall oak	100a	100a	99a	98a	93ab	92ab	91ab
	EKO Shumard oak	100a	92ab	89ab	85abc	82abc	77bcd	73bcd
Welford	Bareroot Nuttall oak	100a	54ef	53ef	53ef	53ef	53ef	53ef
	Bareroot Shumard oak	100a	75bcd	62def	59def	59def	58def	58def
	EKO Nuttall oak	100a	81abc	72bcd	68cde	67cde	67cde	67cde
	EKO Shumard oak	98a	42f	15g	12g	12g	8g	8g

* Values followed by the same letter are not significantly different (α=0.05).

Table 4.6 Seedling mortality related to flooding on the Welford Site by cause, species, and planting stock for 2013 Hurricane Katrina reforestation project.

Stock	Species	Destructive agent: American beaver	Destructive agent: Inundation
		Percent	
Bareroot	Nuttall Oak	45	1
Bareroot	Shumard Oak	21	21
Bareroot	Bareroot combined	33	11
EKO	Nuttall Oak	6	13
EKO	Shumard Oak	16	81
EKO	EKO combined	11	47
	Combined planting stocks	22	29

Species comparison

Significance could not be validly determined for average GLD growth or survival for the main effect species because interactions were detected within species. Significance of average height growth during the first growing season is presented because no interaction was detected within species. Significance could not be validly determined for average height growth during the second growing season or overall because interactions were detected within species.

GLD growth variation between species

Analysis of variance revealed an effect of species on average GLD growth during the first growing season ($F = 161.55$, $p < 0.0001$), the second growing season ($F = 92.23$, $p < 0.0001$), and overall ($F = 105.82$, $p < 0.0001$) (Table 4.1).

Nuttall oak (NUO) seedlings averaged greater GLD growth compared to Shumard oak (SHO) seedlings during the first growing season (NUO 2.7mm, SHO 0.4mm), the second growing season (NUO 5.3mm, SHO 1.9mm) and consequently overall (NUO 8.2mm, SHO 2.6mm) (Table 4.7).

Table 4.7 Average groundline diameter growth by species per growing season and overall for the 2013 Hurricane Katrina reforestation project (both planting stocks and both sites).

	Growing Season		
Species	2014	2015	Overall**
	Millimeters		
Nuttall oak	2.7	5.3	8.2
Shumard oak	0.4	1.9	2.6

** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Height growth variation between species

Analysis of variance revealed a significant effect of species on average height growth during the first growing season ($F = 26.83$, $p < 0.0001$) (Table 4.2). An effect of species on average height was also detected during the second growing season ($F = 14.93$, $p = 0.0001$) and overall ($F = 27.30$, $p < 0.0001$) (Table 4.2), but significance could not be validly determined.

Nuttall oak seedlings also had greater average height growth compared to Shumard oak seedlings during the first growing season (NUO 3.2cm, SHO -2.3cm), the second growing season (NUO 13.1cm, SHO 4.5cm), and overall (NUO 15.6cm, SHO 2.9cm) (Table 4.8). Negative average height growth of Shumard oak seedlings was caused by a combination of individual seedling dieback and second year mortality.

Table 4.8 Average height growth by species per growing season and overall for the 2013 Hurricane Katrina reforestation project (both planting stocks and both sites).

Species	Growing Season 2014	2015	Overall**
	Centimeters		
Nuttall oak	3.2a*	13.1	15.6
Shumard oak	-2.3b	4.5	2.9

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Survival variation between species

Analysis of variance revealed an effect of species on survival at the end of first growing season ($F = 248.41$, $p < 0.0001$) and at the end of the second growing season ($F = 482.66$, $p < 0.0001$) (Table 4.3).

Nuttall oak seedlings had greater survival at the end of both growing seasons (77 percent in 2014, 74 percent in 2015) when compared to Shumard oak seedlings (51 percent in 2014, 37 percent in 2015) (Table 4.9).

Table 4.9 Survival by species at the end of each growing season for the 2013 Hurricane Katrina reforestation project.

Species	End of Growing Season 2014	2015
	Percent	
Nuttall oak	77	74
Shumard oak	51	37

Species comparison discussion

Nuttall oak seedlings maintained greater GLD growth, height growth, and survival throughout this study compared to Shumard oak seedlings. Early growth rate of

Nuttall oak is more rapid than most oak species (Burns and Honkala 1990). Day et al. (1998) and Mercker et al. (2011) found Nuttall oak to have greater growth and survival rates compared to other oaks on poorly drained sites and sites with different flood regimes. Burns and Honkala (1990) listed Shumard oak as being flood intolerant as well as reacting negatively to competition (Burns and Honkala 1990), while Nuttall oak seedlings were listed by Clatterbuck and Meadows (1992) as being able to withstand most competing vegetation. Nuttall oak was also listed by Hook (1984) as being able to survive two months of flooding as seedlings. It is reasonable to assume that Nuttall oak seedlings in this study would perform similarly to other research, and that both inherent growth characteristics and timing of the flood occurrence contributed to its superior growth and survival rates compared to Shumard oak seedlings.

Planting stock comparison

Significance could not be validly determined for average GLD growth or survival for the main effect planting stock because interactions were detected within planting stocks. Significance of average height growth during the second growing season is presented because no interaction was detected within planting stocks. Significance could not be validly determined for average height growth during the second growing season or overall because interactions were detected within planting stocks.

GLD growth variation between planting stocks

Analysis of variance revealed an effect of planting stock on average GLD growth during the first growing season ($F = 30.70$, $p < 0.0001$), but not during the second growing season ($F = 2.93$, $p = 0.0871$) or overall ($F = 2.29$, $p = 0.1307$) (Table 4.1).

EKOgrown® seedlings' average GLD growth was greater than bareroot seedlings during the first growing season (2.1mm and 1.0mm respectively) (Table 4.10). No average GLD growth difference existed between planting stocks during the second growing season (bareroot 3.9mm, EKO 3.3mm) or overall (bareroot 5.0mm, EKO 5.8mm).

Table 4.10 Average groundline diameter growth by planting stock per growing season and overall for the 2013 Hurricane Katrina reforestation project (both species and both sites).

	Growing Season		
Planting stock	2014	2015	Overall**
	Millimeters		
Bareroot seedlings	1.0	3.9	5.0
EKO seedlings	2.1	3.3	5.8

** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Height growth variation between planting stocks

Analysis of variance detected no significant effect of planting stock on average height growth was detected during the first growing season ($F = 0.39$, $p = 0.5301$) (Table 4.2). An effect of planting stock on average height growth was detected during the second growing season ($F = 24.83$, $p < 0.0001$) and overall ($F = 18.76$, $p < 0.0001$), but significance could not be validly determined.

Average height growth did not differ between bareroot seedlings and EKOgrown® seedlings during the first growing season (0.1cm and 0.8cm respectively); however, bareroot seedlings exhibited greater average height growth compared to EKOgrown® seedlings during the second growing season (14.4cm and 3.3cm respectively) and overall (14.5cm and 4.0cm respectively) (Table 4.11).

Table 4.11 Average height growth by planting stock per growing season and overall for the 2013 Hurricane Katrina reforestation project (both species and both sites).

	Growing Season		
Planting stock	2014	2015	Overall**
	Centimeters		
Bareroot seedlings	0.1a*	14.4	14.5
EKO seedlings	0.8a	3.3	4.0

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Survival variation between planting stocks

Analysis of variance revealed an effect of planting stock on survival at the end of the first growing season ($F = 32.38$, $p < 0.0001$) and the second growing season ($F = 24.58$, $p < 0.0001$) (Table 4.3).

At the end of each growing season, survival was greater for bareroot seedlings (69 percent in 2014, 60 percent in 2015) compared to EKOgrown® seedlings (59 percent in 2014, 51 percent in 2015) (Table 4.12).

Table 4.12 Survival by planting stock at the end of each growing season for the 2013 Hurricane Katrina reforestation project (both species and both sites).

	End of Growing Season	
Planting stock	2014	2015
	Percent	
Bareroot seedlings	69	60
EKO seedlings	59	51

Planting stock comparison discussion

Oak seedlings allocate resources to root growth before shoot growth until the root system is large enough to supply nutrients for rapid shoot growth (Johnson et al. 2009).

Bareroot seedlings have less surface area on their roots than EKOgrown® seedlings, and need time to develop root systems capable of supporting shoot growth. Similar to two-year results from Jacobs et al. (2006), EKOgrown® seedlings in this study had greater average GLD growth compared to bareroot seedlings, but average height growth did not differ during the first growing season.

Average GLD growth and average height growth of bareroot seedlings increased dramatically during the second growing season, indicating that bareroot seedlings have established sufficient root systems during the first growing season. Growth rates of bareroot seedlings during the second growing season accelerated so rapidly that, overall, average GLD growth equaled EKOgrown® seedlings and average height growth considerably exceeded EKOgrown® seedlings.

Substantially greater mortality occurred during the first growing season for both planting stocks (31 – 41 percent) compared to the second growing season (8 – 9 percent) (Table 4.12). Most of the mortality during the first growing season can be linked to the flood related factors (bareroot 22 percent, EKO 29 percent) (Table 4.6). Excluding flood related mortality, the first growing season mortality would have been closely comparable to that of the second growing season (bareroot 9 percent, EKO 12 percent).

Site Comparison

Significance could not be validly determined for average GLD growth or survival for the main effect site because interactions were detected within sites. Significance of average height growth during the first growing season is presented because no interaction was detected within sites. Significance could not be validly determined for average height growth during the second growing season or overall because interactions were detected within sites.

GLD growth variation between sites

Analysis of variance revealed an effect of site on average GLD growth during the first growing season ($F = 21.01$, $p < 0.0001$), the second growing season ($F = 45.05$, $p < 0.0001$), and overall ($F = 28.10$, $p < 0.0001$) (Table 4.1).

Average GLD of seedlings planted at the Odom Site was greater than those at the Welford Site during the first growing season (Odom 2.0mm, Welford 1.3mm), the second growing season (Odom 4.8mm, Welford 2.4mm), and overall (Odom 6.9mm, Welford 3.4mm) (Table 4.13).

Table 4.13 Average groundline diameter growth by site per growing season and overall for the 2013 Hurricane Katrina reforestation project (both species and both planting stocks).

	Growing Season		
Site	2014	2015	Overall**
	Millimeters		
Odom Site	2.0	4.8	6.9
Welford Site	1.3	2.4	3.4

** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Height growth variation between sites

Analysis of variance revealed a significant effect of site on average height growth during the first growing season ($F = 9.99$, $p = 0.0016$) (Table 4.2). An effect of site on average height growth was also detected during the second growing season ($F = 37.32$, $p < 0.0001$) and overall ($F = 61.69$, $p < 0.0001$), but significance could not be validly determined.

Average height growth of seedlings at the Odom Site was greater than at the Welford Site during the first growing season (Odom 2.2cm, Welford -1.2cm), the second growing season (Odom 15.6cm, Welford 2.1cm), and overall (Odom 18.8cm, Welford -0.3cm) (Table 4.14). As discussed earlier, dieback and second year mortality are responsible for negative height growth.

Table 4.14 Average height growth by site per growing season and overall for the 2013 Hurricane Katrina reforestation project (both species and both planting stocks).

	Growing Season		
Site	2014	2015	Overall**
	Centimeters		
Odom Site	2.2a*	15.6	18.8
Welford Site	-1.2b	2.1	-0.3

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Survival variation between sites

Analysis of variance revealed an effect of site on survival at the end of the first growing season ($F = 457.98$, $p = <0.0001$) and the second growing season ($F = 355.65$, $p < 0.0001$) (Table 4.3).

Survival at the Odom Site was greater than the Welford Site at the end of the first growing season (Odom 82 percent, Welford 46 percent) and at the end of the second growing season (Odom 72 percent, Welford 39 percent) (Table 4.15).

Table 4.15 Survival by site at the end of each growing season for the 2013 Hurricane Katrina reforestation project (both species and both planting stocks).

	End of Growing Season	
Site	2014	2015
	Percent	
Odom Site	82	72
Welford Site	46	39

Site comparison discussion

Values for all measured variables were greater at the Odom Site than at the Welford Site throughout this research. As discussed in the survival section, the Welford Site experienced a flood, accompanied by beavers, early during the first growing season severely reducing growth and survival rates. Floods that occur during the growing season damage oak seedlings more than dormant season floods, especially when they occur soon after first leaf flush (Broadfoot and Wilson 1973, Baughman 2010). Pezeshki (1996) showed that even though flood tolerant species survived a growing season flood, their growth rates diminished. Beaver herbivory on young oak seedlings has been observed in multiple studies including Lockhart et al. (2000) and Kennedy (1992). This combination of flooding and beaver herbivory explains the sizeable variation in performance between sites.

Interaction of species and planting stock

GLD growth variation by species and planting stock interaction

Analysis of variance revealed that significant interactions were present between species and planting stock affecting average GLD growth during the first growing season ($F = 33.84$, $p < 0.0001$) and the second growing season ($F = 12.96$, $p = 0.0026$), but not overall (F = 0.11, p = 0.7404) (Table 4.1). MCP analysis was then used to determine which interactions were significant.

EKOgrown® Nuttall oak seedlings experienced greater average GLD growth (3.8mm) during the first growing season compared to bareroot Nuttall oak seedlings (1.7mm), but reversed positions in the second growing season with bareroot Nuttall oak seedlings (6.1mm) outgrowing EKOgrown® Nuttall oak seedlings (4.3mm) (Table 4.16). Overall average GLD growth of bareroot and EKOgrown® Nuttall oak seedlings was not significantly different (7.9mm and 8.6mm respectively). No significant difference in average GLD growth was detected between either Shumard oak planting stock during the first growing season (bareroot 0.4mm, EKO 0.3mm), the second growing season (bareroot 1.6mm, EKO 2.3mm), or overall (bareroot 2.0mm, EKO 3.1mm). Both Nuttall oak planting stocks averaged greater GLD growth compared to either Shumard oak planting stock throughout this study.

Table 4.16 Average groundline diameter growth by species and planting stock per growing season and overall for the 2013 Hurricane Katrina reforestation project.

	Growing Season		
Species/Planting stock	2014	2015	Overall**
	Millimeters		
Bareroot Nuttall oak	1.7b*	6.1a	7.9a
Bareroot Shumard oak	0.4c	1.6c	2.0b
EKO Nuttall oak	3.8a	4.3b	8.6a
EKO Shumard oak	0.3c	2.3c	3.1b

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Height growth variation by species and planting stock interaction

Analysis of variance revealed that significant interactions were present between species and planting stock affecting average height growth during the second growing season ($F = 20.74$, $p < 0.0001$) and overall ($F = 22.17$, $p < 0.0001$), but not during the first growing season ($F = 0.33$, $p = 0.5628$) (Table 4.2). MCP analysis was then used to determine which interactions were significant.

During the first growing season, bareroot seedlings of both species displayed greater average height growth (NUO 3.2cm, SHO 3.3cm) than EKOgrown® seedlings of either species (NUO -2.9cm, SHO -1.6cm) (Table 4.17). Bareroot Nuttall oak seedlings expressed considerably greater average height growth compared to all other species and planting stock combinations during the second growing season (23.7cm) and overall (26.6cm). No significant average height growth difference was detected between bareroot Shumard oak seedlings, EKOgrown® Nuttall oak seedlings, or EKOgrown® Shumard oak seedlings during the second growing season (2.5cm, 5.0cm, and 4.1cm respectively) or overall (4.6cm, 2.5cm, and 3.4cm respectively).

Table 4.17 Average height growth by species and planting stock per growing season and overall for the 2013 Hurricane Katrina reforestation project.

	Growing Season		
Species/Planting stock	2014	2015	Overall**
	Centimeters		
Bareroot Nuttall oak	3.2a*	23.7a	26.6a
Bareroot Shumard oak	3.3a	2.5b	4.6b
EKO Nuttall oak	-2.9b	5.0b	2.5b
EKO Shumard oak	-1.6b	4.1b	3.4b

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Survival variation by species and planting stock interaction

Analysis of variance revealed that significant interactions were present between species and planting stock affecting survival during the first growing season ($F = 56.92$, $p < 0.0001$) and the second growing season ($F = 21.77$, $p < 0.0001$) (Table 4.3). MCP analysis was then used to determine which interactions were significant.

No significant difference in survival was evident between either species of bareroot seedlings at the end of the first growing season (NUO 76 percent, SHO 79 percent) or at the end of the second growing season (NUO 75 percent, SHO 74 percent) (Table 4.18). At the end of both growing seasons, survival of EKOgrown® Nuttall oak seedlings (62 percent in 2014, 45 percent in 2015) was less than either species of bareroot seedlings, but greater than EKOgrown® Shumard oak seedlings (40 percent in 2014, 29 percent in 2015).

Table 4.18 Survival by species and planting stock at the end of each growing season for the 2013 Hurricane Katrina reforestation project.

	End of Growing Season	
Species/Planting stock	2014	2015
	Percent	
Bareroot Nuttall oak	76a*	75a
Bareroot Shumard oak	79a	74a
EKO Nuttall oak	62b	45b
EKO Shumard oak	40c	29c

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Interaction of species and planting stock discussion

As discussed earlier, once sufficient root systems were established bareroot seedlings' growth rates matched or exceeded EKOgrown® seedlings, and Nuttall oak generally performed better than Shumard oak. Following a similar pattern, bareroot Nuttall oak seedlings outperformed all other species and planting stock combinations in this study by producing the greatest average height growth, tied for greatest average GLD growth, and tied for greatest survival. Similar results were found when comparing Nuttall oak to live oak in a previous study by Conrad (2013). Survival of EKOgrown® planting stocks continued to decline during the second growing season, while decline in survival of bareroot planting stocks was minor, contradicting results found by Dey et al. (2003). During the current research, EKOgrown® Shumard oak seedlings displayed the poorest performance of all species and planting stock combinations.

Interaction of planting stock and site

GLD growth variation by planting stock and site interaction

Analysis of variance revealed that significant interactions were present between site and planting stock affecting average GLD growth during the second growing season ($F = 9.10$, $p = 0.0026$) and overall ($F = 6.18$, $p = 0.0130$), but not during the first growing season ($F = 0.62$, $p = 0.4321$) (Table 4.1). MCP analysis was then used to determine which interactions were significant.

During the first growing season, EKOgrown® seedlings averaged greater GLD growth compared to bareroot seedlings at the Odom Site (EKO 2.4mm, bareroot 1.5mm) and at the Welford Site (EKO 1.7mm, bareroot 0.5mm) (Table 4.19).

During the second growing season, bareroot seedlings at the Odom Site averaged greater GLD growth compared to EKOgrown® seedlings (5.6mm and 3.9mm respectively), while bareroot and EKOgrown® seedlings at the Welford site average GLD growth was not significantly different (2.2mm and 2.7mm respectively).

Overall, variation was not significant between Odom bareroot seedlings (7.1mm), Odom EKO seedlings (6.6mm), or Welford EKOgrown® seedlings (5.0mm). Average GLD growth of bareroot seedlings at the Welford Site overall (2.8mm) was not significantly different from Welford EKOgrown® seedlings, but was significantly less than both planting stocks at the Odom Site.

Table 4.19 Average groundline diameter growth by planting stock and site per growing season and overall for the 2013 Hurricane Katrina reforestation project.

Planting stock/Site	Growing Season 2014	2015	Overall**
	Millimeters		
Odom bareroot seedlings	1.5b*	5.6a	7.1a
Odom EKO seedlings	2.4a	3.9b	6.6a
Welford bareroot seedlings	0.5c	2.2c	2.8b
Welford EKO seedlings	1.7ab	2.7bc	5.0ab

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Height growth variation by planting stock and site interaction

Analysis of variance revealed that significant interactions were present between species and planting stock affecting average height growth during the second growing season ($F = 19.00$, $p < 0.0001$) and overall ($F = 9.72$, $p = 0.0019$), but were not detected during the first growing season ($F = 0.56$, $p = 0.4551$) (Table 4.2). MCP analysis was then used to determine which interactions were significant.

During the first growing season, average height growth of EKOgrown® seedlings at the Odom Site (2.9cm) was greater than all other site and planting stock combinations; however, it was not significantly different from bareroot seedlings at the same site (1.4mm) (Table 4.20). Average height growth of bareroot seedlings at the Odom Site was also not significantly different from either planting stock at the Welford Site (bareroot - 1.1mm, EKO -1.3mm).

During the second growing season, bareroot seedlings at the Odom Site averaged appreciably greater height growth (26.0mm) compared to all other site and planting stock combinations. No significant difference was detected between EKOgrown® seedlings at the Odom Site (5.2cm) or either planting stock at the Welford Site (bareroot 2.7cm, EKO 1.4cm).

Overall, average height growth of bareroot seedlings at the Odom Site (27.9cm) was greater than EKOgrown® seedlings at the Odom Site (9.8cm). No significant average height growth difference was detected between planting stocks at the Welford Site (bareroot 1.2cm, EKO -1.8cm); although, both experienced significantly less average height growth than either planting stock at the Odom Site.

Table 4.20 Average height growth by planting stock and site per growing season and overall for the 2013 Hurricane Katrina reforestation project.

	Growing Season		
Planting stock/Site	2014	2015	Overall**
	Centimeters		
Odom bareroot seedlings	1.4a*	26.0a	27.9a
Odom EKO seedlings	2.9a	5.2b	9.8b
Welford bareroot seedlings	-1.1b	2.7b	1.2c
Welford EKO seedlings	-1.3b	1.4b	-1.8c

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Survival variation by planting stock and site interaction

Analysis of variance revealed that significant interactions were present between site and planting stock affecting survival at the end of the first growing season ($F = 30.12$, $p < 0.0001$) and the second growing season ($F = 4.57$, $p = 0.0326$) (Table 4.3). MCP analysis was then used to determine which interactions were significant.

At the end of the first growing season, both planting stocks at the Odom Site had significantly greater survival (82 percent each) than bareroot seedlings at the Welford Site (56 percent), and all had greater survival than EKOgrown® seedlings at the Welford Site (37 percent) (Table 4.21).

Survival at the end of the second growing season followed the same trend with no significant difference detected between planting stocks at the Odom Site (bareroot 74 percent, EKO 69 percent), both demonstrating greater survival than bareroot seedlings at the Welford Site (46 percent), and all exhibiting greater survival than EKOgrown® seedlings at the Welford Site (33 percent).

Table 4.21 Survival by planting stock and site at the end of each growing season for the 2013 Hurricane Katrina reforestation project.

	End of Growing Season	
Planting stock/Site	2014	2015
	Percent	
Odom bareroot seedlings	82a*	74a
Odom EKO seedlings	82a	69a
Welford bareroot seedlings	56b	46b
Welford EKO seedlings	37c	33c

* Values in a column followed by the same letter are not significantly different (α=0.05).

Interaction of planting stock and site discussion

For the same reasons discussed in the site comparison section, seedlings at the Odom Site outperformed those at the Welford Site. Both planting stocks at the Odom Site performed acceptably throughout this study; nevertheless, bareroot seedlings at the Odom Site exceeded all other planting stock and site combinations. Both planting stocks at the Welford Site experienced similar height and GLD growth, whereas bareroot seedlings at the site exhibited greater survival compared to EKOgrown® seedlings. EKOgrown® seedlings at the Welford site demonstrated the poorest performance of any planting stock and site combination.

Interaction of species and site

GLD growth variation by species and site interaction

Analysis of variance revealed that significant interactions were present between site and species affecting average GLD growth during the second growing season ($F = 34.42$, $p < 0.0001$) and overall ($F = 10.53$, $p = 0.0012$), but were not detected during the first growing season ($F = 0.01$, $p = 0.9281$) (Table 4.1). MCP analysis was then used to determine which interactions were significant.

Nuttall oak seedlings exhibited greater average GLD growth at the Odom site throughout this research (3.2mm in 2014, 7.5mm in 2015, and 10.6mm overall) compared to the Welford Site (2.3mm in 2014, 3.1mm in 2015, and 5.9mm overall) (Table 4.22).

No significant difference in average GLD growth of Shumard oak seedlings was detected during any period between the Odom Site (0.8mm in 2014, 2.1mm in 2015, and 3.1mm overall) and the Welford Site (-0.1mm in 2014, 1.8mm in 2015, and 2.0mm overall). Average GLD growth of Nuttall oak seedlings was significantly greater than Shumard oak seedlings during each period regardless of site.

Table 4.22 Average groundline diameter growth by species and site per growing season and overall for the 2013 Hurricane Katrina reforestation project.

	Growing Season		
Species/Site	2014	2015	Overall**
	Millimeters		
Odom Nuttall oak	3.2a*	7.5a	10.6a
Welford Nuttall oak	2.3b	3.1b	5.9b
Odom Shumard oak	0.8c	2.1c	3.1c
Welford Shumard oak	-0.1c	1.8c	2.0c

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Height growth variation by species and site interaction

Analysis of variance revealed no interaction between species and site for average height growth during the first growing season ($F = 1.59$, $p = 0.2070$), the second growing season ($F = 3.13$, $p = 0.0769$), or overall ($F = 3.29$, $p = 0.0698$) (Table 4.3).

Nuttall oak seedlings at the Odom Site had greater average height growth than any other species and site combination throughout this research (5.6cm in 2014, 21.9cm in 2015, and 27.4cm overall) (Table 4.23).

During the first growing season, no significant difference was detected in average height growth of Shumard oak at the Odom Site (-1.3cm) or between either species at the Welford Site (NUO 0.9cm, SHO -3.3cm).

During the second growing season, Shumard oak seedlings at the Odom Site had significantly greater average height growth (9.4cm) than Nuttall oak at the Welford Site (4.4cm), and both had greater average height growth than Shumard oak at the Welford Site (-0.3cm).

Overall, Shumard oak seedlings at the Welford Site had less average height growth (-4.4cm) compared to Nuttall oak seedlings at the Welford Site (3.8cm), and both had significantly less average height growth than Shumard oak seedlings at the Odom Site (10.3cm).

Table 4.23 Average height growth by species and site per growing season and overall for the 2013 Hurricane Katrina reforestation project.

	Growing Season		
Species/Site	2014	2015	Overall**
	Centimeters		
Odom Nuttall oak	5.6a*	21.9a	27.4a
Welford Nuttall oak	0.9b	4.4c	3.8c
Odom Shumard oak	-1.3b	9.4b	10.3b
Welford Shumard oak	-3.3b	-0.3d	-4.4d

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Survival variation by species and site interaction

Analysis of variance revealed no significant interaction between species and site affecting survival at the end of the first growing season ($F = 0.21$, $p = 0.6505$) or the second growing season ($F = 0.01$, $p = 0.9226$) (Table 4.3).

Nuttall oak seedlings at the Odom Site exhibited excellent survival throughout the research (95 percent in 2014, 91 percent in 2015), which was greater than all other species and site combinations (Table 4.24).

At the end of the first growing season, survival of Shumard oak seedlings at the Odom Site (69 percent) and Nuttall oak seedlings at the Welford Site (60 percent) were both greater than Shumard oak seedlings at the Welford Site (33 percent).

At the end of the second growing season, no significant difference in survival was detected between Nuttall oak seedlings at the Welford Site (58 percent) and Shumard oak seedlings at the Odom Site (53 percent), which both exhibited greater survival than Shumard oak seedlings at the Welford Site (21 percent).

Table 4.24 Survival by species and at the end of each growing season for the 2013 Hurricane Katrina reforestation project.

	End of Growing Season	
Species/Site	2014	2015
	Percent	
Odom Nuttall oak	95a*	91a
Welford Nuttall oak	60b	58b
Odom Shumard oak	69b	53b
Welford Shumard oak	33c	21c

* Values in a column followed by the same letter are not significantly different (α=0.05).

Interaction of species and site discussion

Nuttall oak seedlings at the Odom Site produced the best performance of all species and planting stock combinations throughout this study, while Shumard oak seedlings at the Welford Site displayed the poorest. As discussed in the species comparison section, Nuttall oak is a superior early competitor to Shumard oak in saturated or flooded soils. Results of this study correspond to those mentioned in the site comparison section found by Broadfoot and Wilson (1974), Baughman (2010), and Pezeshki (1996). The authors stated that trees are most susceptible to early growing season floods just after their first flush of growth, and even flood tolerant species may exhibit diminished survival and sluggish growth rates following complete inundation during the growing season within a short time of planting. Even though Shumard oak was not expected to perform as well as Nuttall oak, the sizeable separation in productivity between species at the Odom Site was not anticipated, and it demonstrated the lasting effects that delaying early growth can have on seedling performance.

Interaction of site and treatment

GLD growth variation by site and treatment interaction

Analysis of variance revealed that significant interactions were present among species, planting stock, and site variables affecting average GLD growth during the first growing season ($F = 5.37$, $p = 0.0207$), but were not detected during the first growing season ($F = 0.80$, $p = 0.3720$) or overall ($F = 2.16$, $p = 0.1420$) (Table 4.1). MCP analysis was then used to determine which interactions were significant.

No significant difference was detected during the first growing season at the Odom Site between either species of EKO seedlings (NUO 4.0mm, SHO 3.7mm), both of which exhibited greater average GLD growth than bareroot Nuttall oak seedlings (2.4mm), and all averaged greater GLD growth than bareroot Shumard oak seedlings (1.0mm) (Table 4.25).

During the first growing season at the Welford Site, no significant difference in average GLD growth was detected among treatments with bareroot Nuttall oak seedlings averaging 0.7mm, bareroot Shumard oak seedlings averaging 0.1mm, EKO Nuttall oak seedlings averaging 1.0mm, and EKOgrown® Shumard oak seedlings averaging -0.2mm. Negative GLD growth is conceivable, and may be explained by harsh conditions at the site (wet spring/dry summer, acidic soil, and below average nutrient availability) causing seedlings to shrink after being transplanted from ideal conditions at the nursery. At the end of the first growing season, only eight percent of EKOgrown® Shumard oak seedlings survived at the Welford Site rendering their results statistically incomparable.

The greatest average GLD growth occurring during the first growing season was achieved by both species of EKOgrown® seedlings at the Odom site, followed by bareroot Nuttall oak seedlings at the Odom Site, then by all other treatments at either site.

During the second growing season at the Odom Site, no significant average GLD growth difference was detected between Shumard oak seedlings of either planting stock (bareroot 3.3mm, EKO 2.8mm), which both averaged less GLD growth than EKOgrown® Nuttall oak seedlings (5.6mm), and were all less than bareroot Nuttall oak seedlings (9.1mm).

During the second growing season at the Welford Site, no significant differences in average GLD growth were detected among any treatments with bareroot Nuttall oak seedlings averaging 2.1mm, bareroot Shumard oak seedlings averaging 1.1mm, EKOgrown® Nuttall oak seedlings averaging 2.0mm, and EKOgrown® Shumard oak seedlings averaging 2.5mm. Survival of EKOgrown® Shumard oak seedlings dropped even lower during the second growing season to only three percent, and they remained statistically incomparable to results of other treatments.

During the second growing season, bareroot Nuttall oak at the Odom site produced the greatest average GLD growth of all treatments at either site, followed by EKOgrown® Nuttall oak at the Odom Site, and then by both Shumard oak planting stocks at the Odom Site. All treatments at the Welford Site grew less average GLD growth than any treatment at the Odom Site during the second growing season; however, difference between Shumard oak planting stocks at the Odom Site and Nuttall oak planting stocks at the Welford Site was not significant.

Overall, average GLD growth at the Odom Site was significantly different for every treatment. Bareroot Nuttall oak seedlings at the Odom Site had the greatest overall average GLD growth (11.4mm) of any treatment, followed by EKOgrown® Nuttall oak seedlings (9.8mm), then by EKOgrown® Shumard oak seedlings (7.3mm), and then bareroot Shumard oak seedlings (4.5cm).

GLD growth on the Welford Site followed the same trend overall with both growing seasons exhibiting no significant difference among any treatments. Bareroot Nuttall oak seedlings averaged 2.9mm, bareroot Shumard oak seedlings averaged 1.2mm, EKOgrown® Nuttall oak seedlings averaged 3.4mm, and EKOgrown® Shumard oak seedlings averaged 2.8mm. As stated previously, EKOgrown® Shumard oak seedlings at the Welford Site are not statistically comparable to other treatments due to mortality.

Overall, bareroot Nuttall oak seedlings at the Odom Site had the greatest average GLD growth of any treatment at either site. All treatments at the Odom Site possessed greater overall average GLD growth compared to any treatment at the Welford Site; however, bareroot Shumard oak seedlings at the Odom Site did not differ significantly from either planting stock of Nuttall oak seedlings at the Welford Site.

Table 4.25 Average groundline diameter growth by treatment and site per growing season and overall for the 2013 Hurricane Katrina reforestation project.

Site	Treatment	2014	2015	Overall**
		Millimeters		
Odom	Bareroot Nuttall oak	2.4b*	9.1a	11.4a
Odom	Bareroot Shumard oak	1.0c	3.3c	4.5d
Odom	EKO Nuttall oak	4.0a	5.6b	9.8b
Odom	EKO Shumard oak	3.7a	2.8cd	7.3c
Welford	Bareroot Nuttall oak	0.7c	2.1cde	2.9de
Welford	Bareroot Shumard oak	0.1c	1.1e	1.2e
Welford	EKO Nuttall oak	1.0c	2.0de	3.4de
Welford	EKO Shumard oak	-0.2***	2.5***	2.8***

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.
*** Insufficient amount remain for analysis.

Height growth variation by site and treatment interaction

Analysis of variance revealed that significant interactions were present among species, planting stock, and site variables affecting average height growth during the second growing season (F = 12.05, p = 0.0005) and overall (F = 8.24, p = 0.0042), but were not detected during the first growing season (F = 0.11, p = 0.7393) (Table 4.2). MCP analysis was then used to determine which interactions were significant.

During the first growing season at the Odom Site, no significant difference in average height growth was detected in planting stocks of the same species; however, both Nuttall oak planting stocks produced greater average height growth (bareroot 5.0cm, EKO 6.2cm) compared to either Shumard oak planting stock (bareroot -0.4cm, EKO -2.1cm) (Table 4.26).

The Welford Site also experienced no significant difference in average height growth between planting stocks of the same species during the first growing season, and both Nuttall oak planting stocks (bareroot 1.4cm, EKO 0.3cm,) exhibited greater average height growth than either Shumard oak planting stock (bareroot -3.7cm, EKO -2.9cm). As explained in earlier sections, negative height growth is a result of dieback and second year mortality, and EKOgrown® Shumard oak seedlings at the Welford Site are not statistically comparable to other treatments.

The greatest average height growth during the first growing season was shared by both Nuttall oak planting stocks at the Odom Site, followed by both Nuttall oak planting stocks at the Welford Site, then by all Shumard oak seedlings regardless of planting stock or site.

During the second growing season at the Odom Site, bareroot Nuttall oak seedlings had the greatest average height growth (41.1cm) of all treatments on the site, followed by both planting stocks of Shumard oak seedlings (bareroot 10.8cm, EKO 7.9cm), and EKOgrown® Nuttall oak seedlings (2.6cm).

Bareroot Nuttall oak seedlings at the Welford site also produced the greatest average height growth of any treatment during the second growing season (6.3cm), followed by EKOgrown® Nuttall oak seedlings (2.5cm), and both Shumard oak planting stocks (bareroot -0.8cm, EKO 0.2cm).

Bareroot Nuttall oak at the Odom Site exhibited the greatest average height growth of any treatment at either site during the second growing season, followed by both Shumard oak planting stocks at the Odom Site and bareroot Nuttall oak seedlings at the Welford site, and EKOgrown® Nuttall oak seedlings at both sites. Both Shumard oak planting stocks at the Welford Site had the least average height growth observed.

Overall, bareroot Nuttall oak seedlings at the Odom Site produced substantially greater average height growth (45.6cm) compared to all other treatments (bareroot SHO 10.1cm, EKO NUO 9.1cm, EKO SHO 10.4cm), none of which were found to differ.

At the Welford Site, overall average height growth was also greatest for bareroot Nuttall oak seedlings (7.6cm) compared to all other treatments (bareroot SHO -5.2cm, EKO NUO 0.1cm, EKO SHO -3.7cm), but EKOgrown® Nuttall oak seedlings' average height growth was greater than both Shumard oak planting stocks.

Bareroot Nuttall oak at the Odom Site maintained the greatest overall average height growth of all treatments at either site, followed by all other treatments at the Odom Site and bareroot Nuttall oak seedlings at the Welford Site, EKOgrown® Nuttall oak seedlings at the Welford Site, and Shumard oak planting stocks at the Welford Site.

Table 4.26 Average height growth by treatment and site per growing season and overall for the 2013 Hurricane Katrina reforestation project.

Site	Treatment	Growing Season 2014	Growing Season 2015	Growing Season Overall**
		Centimeters		
Odom	Bareroot Nuttall oak	5.0a*	41.1a	45.6a
Odom	Bareroot Shumard oak	-2.1cd	10.8b	10.1b
Odom	EKO Nuttall oak	6.2a	2.6c	9.1b
Odom	EKO Shumard oak	-0.4c	7.9b	10.4b
Welford	Bareroot Nuttall oak	1.4b	6.3b	7.6b
Welford	Bareroot Shumard oak	-3.7d	-0.8d	-5.2d
Welford	EKO Nuttall oak	0.3bc	2.5c	0.1c
Welford	EKO Shumard oak	-2.9***	0.2***	-3.7***

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.
*** Insufficient amount remain for analysis.

Survival variation by site and treatment interaction

Analysis of variance revealed that significant interactions were present among species, planting stock, and site variables affecting survival at the end of the first growing season ($F = 142.42$, $p < 0.0001$) and the second growing season ($F = 78.25$, $p < 0.0001$) (Table 4.3). MCP analysis was then used to determine which interactions were significant.

Survival at the Odom Site did not differ significantly between planting stocks of the same species at the end of the first growing season. Both planting stocks of Nuttall oak seedlings (bareroot 98 percent, EKO 91 percent) exhibited greater survival than either Shumard oak planting stock (bareroot 66 percent, EKO 73 percent) (Table 4.27).

At the end of the first growing season, survival at the Welford Site was not significantly different for either species of bareroot seedlings (NUO 53 percent, SHO 58 percent) or EKOgrown® Nuttall oak seedlings (67 percent), which all had greater survival than EKOgrown® Shumard oak seedlings (8 percent).

At the end of the first growing season, survival was greatest for Nuttall oak seedlings at the Odom Site regardless of planting stock, and poorest for EKOgrown® Shumard oak seedlings at the Welford Site.

At the end of the second growing season, bareroot Nuttall oak seedlings at the Odom Site exhibited the greatest survival observed for either species at either site. No significant difference in survival was present between either Shumard oak planting stock at the Odom Site (bareroot 52 percent, EKO 54 percent), which both experienced less survival than EKOgrown® Nuttall oak seedlings (85 percent).

No difference was detected between survival of either Nuttall oak planting stock at the Welford site (EKO 64 percent, bareroot 53 percent), while both had greater survival than bareroot Shumard oak seedlings (38 percent), and all exhibited greater survival than EKOgrown® Shumard oak seedlings (3 percent).

Bareroot Nuttall oak seedlings at the Odom Site had the greatest survival of all treatments at the end of the second growing season, followed by EKOgrown® Nuttall oak seedlings at the Odom Site, and EKOgrown® Shumard oak seedlings at the Welford site continued to have the poorest survival of all treatments at either site.

Table 4.27 Survival by treatment and site at the end of each growing season for the 2013 Hurricane Katrina reforestation project.

Site	Treatment	End of Growing Season 2014	End of Growing Season 2015
		Percent	
Odom	Bareroot Nuttall oak	98a*	97a
Odom	Bareroot Shumard oak	66bc	52c
Odom	EKO Nuttall oak	91a	85b
Odom	EKO Shumard oak	73b	54c
Welford	Bareroot Nuttall oak	53c	53c
Welford	Bareroot Shumard oak	58c	38d
Welford	EKO Nuttall oak	67bc	64c
Welford	EKO Shumard oak	8d	3e

* Values in a column followed by the same letter are not significantly different (α=0.05).
** Overall results may slightly differ from sum of both growing seasons due to additive mortality.

Interaction of site and treatment discussion

Bareroot Nuttall oak seedlings at the Odom Site performed best of all treatments at either site, while EKOgrown® Shumard oak seedlings at the Welford Site had such poor survival that growth was statistically irrelevant. Although performance of each treatment was greater at the Odom Site, treatments followed similar trends at both sites. Performance of bareroot Nuttall oak seedlings exceeded all other treatments, and performance of EKOgrown® Nuttall oak seedlings exceeded both Shumard oak planting stocks. At each site, Shumard oak planting stocks performed similarly, with the exception of EKOgrown® seedlings' poor survival at the Welford Site.

CHAPTER V

CONCLUSION

Hodges (1994) explained the importance of matching species to the correct site, and that elevation differences as small as 60cm to 90cm can change species suitability in bottomlands. Nuttall oak is well suited for bottomland hardwood restoration in the southeastern United States, and may be a better choice than Shumard oak because Shumard oak does not tolerate flooding, saturated soils, and competing vegetation as well. Though flooding, saturated soils, and competing vegetation are not always present in bottomlands, they are abundant in the Southeast and further emphasize the importance of matching the correct species to the site.

As evidenced in this study, even after providing precautionary measures to ensure successful seedling establishment, some events are beyond human control. These measures are still the key in providing consistent successful establishment. However, when events such as the ones experienced in this study occur, those measures become essential in minimizing damage to the seedlings.

Grossman et al. (2003) stated that RPM® seedlings (comparable to EKOgrown® seedlings) had several advantages over bareroot seedlings including flood tolerance along with improved growth and survival, yet opposing results were found in this research.

Inundation mortality was over four times more likely to occur with EKOgrown® seedlings compared to bareroot seedlings; although, beaver predation was three times less likely to occur with EKOgrown® seedlings compared to bareroot seedlings. With those results in mind, EKOgrown® seedlings may prove beneficial in areas where semi-aquatic rodent predation is a major concern.

Excluding the slightly greater average GLD growth of EKOgrown® seedlings during the first growing season, growth and survival of bareroot seedlings matched or surpassed EKOgrown® seedlings throughout this research. Through two growing seasons, bareroot seedlings, if matched to the site, appear to give the greatest survival and growth of all planting stocks. Bareroot seedlings cost substantially less than EKOgrown® seedlings, and are therefore believed to be the most cost-effective option for artificial reforestation of bottomland oaks in the southeastern United States.

REFERENCES

Alkire, D.K. 2011. *Artificial regeneration of bottomland hardwoods in southern Mississippi on lands damaged by Hurricane Katrina*. M.Sc. thesis, Mississippi State University, Mississippi State, MS, USA. 54 p.

Allen, J.A., B.D. Keeland, J.A. Stanturf, A.F. Clewell, and H.E. Kennedy. 2001. A guide to bottomland hardwood restoration. USDA Forest Service, Southern Research Station, Asheville, NC. 132 p.

Allen, J.A. and H.E. Kennedy. 1989. Bottomland hardwood reforestation in the lower Mississippi valley. Fish and Wildlife Service and Forest Service, Slidell, LA and Stoneville, MS. 29 p.

Anderson, P.H. and S.R. Pezezhki. 1999. The effects of intermittent flooding on seedlings of three forest species. *Photosynthetica*. 37:543-552

Baker, B.W. and E.P. Hill. 2003. Beaver. P. 288-310 in *Wild mammals of North America: biology, management, and conservation*. Felderman, G.A., B.C. Thompson, and J.A. Chapman (eds.) John Hopkins University Press, Baltimore, Maryland.

Baker, B.W. and W.M. Broadfoot. 1979. *A practical field method of site evaluation for commercially important southern hardwoods*. USDA Forest Service, Southern Forest Experiment Station, New Orleans, LA. Gen. Tech. Rep. SO-26. 51p.

Barney, D.L. 1991. *Winter protection for containerized nursery stock*. University of Idaho, Agricultural Experiment Station. current information series 892. 4 p.

Baughman, M. 2010. *Flooding effects on trees*. Available online at http://www.extension.umn.edu/environment/trees-woodlands/flooding-effects-on-trees/; last accessed December 1, 2015.

Bigras, F.J. and D. Dumais. 2005. Root-freezing damage in the containerized nursery: impact on planting sites – a review. *New Forests*. 30:167-184.

Blake, E.S., C.W. Landsea, and E.J. Gibney. 2011. *The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2010 (and other frequently requested hurricane facts).* National Oceanic and Atmospheric Administration. Tech. Mem. NWS NHC-6. 47 p.

Bonner, F.T. 1974. *Chemical components of some southern fruits and seeds*. USDA Forest Service, Southern Forest Experiment Station. Research note SO-183. 3 p.

Bried, J.T. and N.A. Gifford. 2010. Mowing and herbicide of scrub oaks in pine barrens: baseline data (New York). *Ecological Restoration*. 28(3):245-248.

Broadfoot, W.M. and H.L. Wilson. 1973. Flooding effects on southern forest. *Journal of Forestry*. 71(9):584-587.

Bullard, S., J.D. Hodges, R.L. Johnson, and T.J. Straka. 1992. Economics of direct seeding and planting for establishing oak stands on old-field sites in the South. *Southern Journal of Applied Forestry*. 16:34-39.

Burkett, V.R. and H.M. Williams. 1998. Effects of flooding regime, mycorrhizal inoculation and seedling treatment type on first-year survival of Nuttall oak (*Quercus nuttallii* Palmer). P. 289-294 in Proc. of *ninth biennial southern silviculture research conference*, Waldrop, T.A. (ed.). USDA Forest Service, Southern Research Station, Asheville, NC.

Burkett, V.R., R.O. Draugelis-Dale, H.M. Williams, and S.H. Schoenholtz. 2005. Effects of flooding regime and seedling treatment on early survival and growth of Nuttall oak. *Restoration Ecology.* 13(3):471-479.

Burns, R.M., and B.H. Honkala. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p

Conrad, J.A. 2013. *Early survival and growth performance of two oak species and three planting stocks on Hurricane Katrina disturbed lands*. M.Sc. thesis, Mississippi State University, Mississippi State, MS, USA. 76 p.

Clatterbuck, W.K. and J.S. Meadows. 1992. Regenerating oaks in the bottomlands. P. 184-195 om Proc of *oak regeneration: serious problems practical recommendations*, Loftis, D.L. and C.E. McGee (eds.), USDA Forest Service, Southeastern Forest Experiment Station. Asheville, NC.

Day, C.P. III, J.D. Hodges, S.H. Schoenholtz, and K.L. Belli. 1998. Influence of hydrology on artificial regeneration of oaks in the Mississippi Delta. P. 295-299 in Proc. of *ninth biennial southern silviculture research conference*, Waldrop, T.A. (ed.). USDA Forest Service, Southern Research Station, Asheville, NC.

Dey, D.C., J. Douglass, K. McNabb, G. Miller, V. Baldwin, and G. Foster. 2008. Artificial regeneration of major oak (*Quercus*) species in the eastern United States – A review of the literature. *Forest Science.* 54(1): 77-105.

Dey, D.C., J.M. Kabrick, M.A. Gold. 2003. Tree establishment in floodplain agroforestry practices. P. 102-115 in Proc of *eighth North American agroforestry conference*. Sharrow, S.H. (ed.). Oregon State University, Corvallis, OR.

Dey, D.C., J.M. Kabrick, M.A. Gold. 2006. The roll of large container seedlings in afforesting oaks in bottomlands. P. 218-223 in Proc. of *13th biennial southern silvicultural research conference*, Connor, K.F. (ed.) USDA Forest Service, Southern Research Station, Asheville, NC.

Dumroese, R.K. and P.W. Owston. 2003. A user's guide to nursery stock types. *Western Forester* 4-5.

EKOgrown. 2015. Available online at www.ekosystemspartners.org/trees.html; last accessed October 12, 2015.

Ezell, A.W. 2014. *Direct seeding: A forest regeneration alternative*. Available online at www.msucares.com/pubs/publications/p1588.htm; last accessed July 18, 2014.

Ezell, A.W. and J.D. Hodges. 2002. Herbaceous weed control improves survival of planted Shumard oak seedlings. P. 273-275 in Proc. of *11th biennial southern silviculture research conference*, Outcalt, K.W. (ed.). USDA Forest Service, Southern Research Station, Asheville, NC.

Ezell, A.W., J.L. Yeiser, and L.R. Nelson. 2007. Survival of planted oak seedlings in improved by herbaceous weed control. *Weed Technology* 21:175-178.

Food Security Act of 1985. 1985. 99th Congress. 99 Stat 1354. 307 p.

Forest Keeling Nursery. 2014. *What is RPM®*. Available online at http://www.fknursery.com/index.cfm/fuseaction/home.showpage/pageID/18/index.htm; last accessed July 18, 2014.

Gardiner, E.S., K.F. Salifu, D.F. Jacobs, G. Hernandez, and R.P. Overton. 2007. Field performance of Nuttall oak on former agriculture fields: initial effects of nursery source and competition control. P. 120-125 in Proc of *forest and conservation nursery associations*, Riley, L.E., R.K. Dumroese, and T.D. Landis (eds.). USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Gazal, R.M. and M.E. Kubiske. 2004. Influence of initial root length on physical responses of cherrybark oak and Shumard oak seedlings to field drought conditions. *Forest Ecology and Management*. 189:295-305.

Grossman, B.C., M.A. Gold, and D.C. Dey. 2003. Restoration of hard mast species for wildlife in Missouri using precocious flowering oak in the Missouri River floodplain, USA. *Agroforestry Systems*. 59:3-10.

Hanberry, B.B., J. M. Kabrick, H. S. He, and B. J. Palik. 2012. Historical trajectories and restoration strategies for the Mississippi River Alluvial Valley. *Forest Ecology and Management.* 280: 103-111.

Haynes, R. J. 2004. The development of bottomland forest restoration in the lower Mississippi River Alluvial Valley. *Ecological Restoration.* 22(3): 170-182.

Hodges, J.D. 1994. Ecology of bottomland hardwoods. P. 5-11 in Proc. of *a workshop to resolve the conservation of migratory landbirds in bottomland hardwood forest*, Smith, W.P. and D.N. Pashley (eds.). USDA Forest Service, Southern Forest Experiment Station, New Orleans, LA.

Hodges, J.D., D.L. Evans, and L.W. Garnett. 2008. Mississippi trees. Mississippi State University, Extension Service, Mississippi State, Mississippi. 37 p.

Hook, D.D. 1984. Waterlogging tolerance of lowland tree species of the South. *Southern Journal of Applied Forestry*. 8(3):136-149.

Humphrey, M., B.A. Kleiss, and H.N. Williams. 1993. *Container oak seedlings for bottomland hardwood (BLH) restoration*. Wildlife Reserve Program Tech. Note VN-EM-1.1. 5 p.

Hurricane Katrina. 2014. *Funk and Wagnall's New World Encyclopedia*. Available online at http://eds.b.ebscohost.com/eds/detail/detail?vid=22&sid=23dea74e-21a5-4f73-b1a8-2eb4d09bdade%40sessionmgr198&hid=108&bdata=nNpdGU9ZWRzLWxpmU%3d#AN=HU111475&db=funk; last accessed July 18, 2014.

Jacobs, D.F. 2003. *Nursery production of hardwood seedlings*. USDA For. Serv. Gen. Tech. Rep. FNR-212. 8 p.

Jacobs, D.F., R.A. Rathfon, A.S. Davis, and D.E. Carlson. 2006. Stocktype and harvest gap size influence northern red oak regeneration success. P. 247-250 in Proc. of *13th biennial southern silvicultural research conference,* Conner K.F. (ed.). USDA Forest Service, Southern Research Station, Asheville, NC.

Johnson, P.S. 1992. Sources of oak reproduction. P. 112-131 in Proc. of *oak regeneration: serious problems practical recommendations*, D.L. Loftis and C.E. McGee (eds.). USDA Forest Service, Southern Forest Experiment Station, Asheville, NC.

Johnson, P.S., S.R. Shifley, and R. Rogers. 2009. The Ecology and Silviculture of Oaks. CAB International, Wallingford, Oxfordshire, UK.

Johnson, R.L. 1981. Wetland silviculture systems. P. 63-79 in Proc. of *30th Annual Forestry Symposium*. Jackson, B.D. and J.L. Chambers (eds.). Louisiana State University, Baton Rouge, LA.

Kennedy, H.E. 1992. Artificial regeneration of bottomland oaks. P. 241-249 in Proc. of *oak regeneration: serious problems practical recommendations*, D.L. Loftis and C.E. McGee (eds.). USDA Forest Service, Southern Forest Experiment Station, Asheville, NC.

Kennedy, H.E. and R.M. Krinard. 1985. *Shumard oak successfully planted on high pH soils*. USDA Forest Service, Southern Forest Experiment Station. Research note SO-321. 3 p

King, S. and L. Fredrickson. 1998. Bottomland Hardwood Guidebook: The Decision Making Process, Design, Management, and Monitoring of GTR's. Environmental Protection Agency, Dallas, TX. 31 p.

Kormanik, P.P., R.P. Belanger, and E.W. Belcher. 1976. Survival and early growth of containerized and bareroot seedlings of cherrybark oak. *Tree Planters Notes* 27(3):9-11.

Krinard, R.M. and R.L. Johnson. 1981. *Flooding, beavers, and hardwood seedling survival.* USDA Forest Service, Southern Forest Experiment Station. Research note RN-270. 6 p.

Lockhart, B.R., J.D. Hodges, and E.S. Gardiner. 2000. Response of advance cherrybark oak reproduction to midstory removal and shoot clipping. *Southern Journal of Applied Forestry*. 24(1):45-50.

Landis, T.D., R.K. Dumroese, and D.L. Haase. 2010. Seedling processing, storage, and outplanting. USDA Forest Service. Washington, DC. 200 p.

Larsen, D. and P.S. Johnson. 1998. Linking the ecology of oak regeneration to silviculture. *Forest Ecology and Management*. 106:1-7.

Marquis, D.A., P.L. Eckert, and B.A. Roach. 1976. Acorn weevils, rodents, and deer all contribute to oak-regeneration difficulties in Pennsylvania. USDA Forest Service Rep. NE-308. 8 p.

McLeod, K.W., J.K. Cameron, and W.H. Conner. 1999. Photosynthesis and water relations of four oak species: impact of flooding and salinity. *Trees*. 13:178-187.

Meadows, J.S. and J.A. Stanturf. 1997. Silviculture systems for southern bottomland hardwood forest. *Forest Ecology and Management.* 90:127-140.

Mercker, D., D. Tyler, and J. Smith. 2011. A guide for matching oak species with sites during restoration of loess-influenced bottomlands in the West Gulf Coast Plain. University of Tennessee, Extension Service, Knoxville, TN.

Mississippi Department of Agriculture and Commerce. 2014. *Mississippi agriculture overview*. Available online at https://www. Mdac.ms.gov/agency-info/Mississippi-agriculture-snapshot/; last accessed June 5, 2015.

Mullin, S.J. and R.J. Cooper. 2002. Barking up the wrong tree. *Canadian Journal of Zoology*. 80:591-595.

North American Bird Conservation Initiative, U.S. Committee. 2015. *2014 Farm Bill Field Guide to Fish and Wildlife Conservation*. Jodi Stemler Consulting, LLC. 58 p.

NRCS. 2015. *Financial assistance*. Available online at www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/; last accessed June 18, 2015.

Oswalt, S.N. 2015. *Forests of Mississippi, 2014*. USDA Forest Service, Southern Research Station resource update FS-49. 4 p.

Pezeshki, S.R. 1996. Responses of three bottomland species with different flood tolerance capabilities to various flood regimes. *Wetlands Ecology and Management*. 4(4):245-256.

Prestemon, J.P. and T.P. Holmes. 2010. *Economic impacts of hurricanes on forest owners*. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-802. P. 207-221.

Rewa, C. 2000. Biological responses to wetland restoration: implications for wildlife habitat development through the Wetlands Reserve Program. P. 95-116 in *a comprehensive review of farm bill contributions to wildlife conservation, 1985-2000*, Hohman, W.L. and D.J. Halloum (eds.). USDA, NRCS, Wildlife Habitat Management Institute, Madison, MS.

Ruzicka, K.J., J.W. Groninger, and J.J. Zaczek. 2007. Deer browsing patterns in a recently afforested bottomland. P. 612-617 in Proc. of *15th Central Hardwoods Forestry Conference*. Buckley, D.S. and W.K. Clatterbuck (eds.). USDA Forest Service, Southern Research Station, Knoxville, TN.

Schoenholtz, S.H., J.A. Stanturf, J.A. Allen, and C.J. Schweitzer. 2005. Afforestation of agricultural lands in the lower Mississippi alluvial valley. P. 413-441 in Proc. of *ecology and management of bottomland hardwood systems: the state of our understanding*, Fredrickson, L.H., S.L. King, and R.M. Kaminski (eds.). University of Missouri-Columbia, Puxico, MO.

Self, A.B. 2011. *Evaluation of mechanical site preparation and Oust XP treatments on survival and growth of three oak species planted on retired agricultural areas and a case study of a mixed Nuttall oak-green ash planting*. Ph.D. dissertation, Mississippi State University, Mississippi State, MS, USA. 76 p.

Self, A.B., A.W. Ezell, A.J. Londo, and J.D. Hodges. 2010. Evaluation of Nuttall oak and cherrybark oak survival by planting stock and site preparation treatment type in a WRP planting on a retired agricultural site. P. 159-163 in Proc. of *14th biennial southern silviculture conference*, Stanturf, J.A. (ed.). USDA Forest Service, Southern Research Station, Asheville, NC.

Self, A.B., A.W. Ezell, A.J. Londo, J.D. Hodges, and D.K. Alkire. 2013. Effects of chemical site preparation on herbaceous vegetation prior to hardwood plantation establishment. P. 302-307 in Proc of *16th biennial southern silviculture research conference*, Butnor, J.R. (ed.). USDA Forest Service, Southern Research Station, Asheville, NC.

Self, A.B., A.W. Ezell, D.B. Hollis, and D.K. Alkire. 2011. Effect of mechanical site preparation treatments on oak survival in a retired field afforestation effort – First year results. P. 314-322 in Proc. of *17th central hardwood forest conference*, Fei, S., J.M. Lhotka, J.W. Stringer, K.W. Gottschalk, and G.W. Miller (eds.). USDA Forest Service, Northern Research Station, Newtown Square, PA.

Self, A.B., A.W. Ezell, D. Rowe, E.B. Schultz, and J.D. Hodges. 2012. Effects of mechanical site preparation on growth of oaks planted on former agricultural fields. *Forests*. 3:22-32.

Seifert, J.R., M.F. Selig, and R.C. Morrisey. 2007. Weed competition control in hardwood plantations. Purdue University, Cooperative Extension Service, West Lafayette, IN. FNR-224.

Smith, D.M. 1962. The practice of silviculture. John Wiley & Sons Inc., New York, USA. 578 p.

Stanturf, J.A and J.S. Meadows. 1994. Natural regeneration of southern bottomland hardwoods. P. 6-11 in Proc. of *southern regional council on forest engineering annual meeting*, Egan, A.F. (ed.), Mississippi State University, Mississippi State, MS.

Toliver, J.R. and B.D. Jackson. 1989. Recommended silvicultural practices in southern wetland forests. P. 72-80. In Proc. of *the forested wetlands of the southern United States*, Hook, D.D. and R. Lea (eds.). USDA Forest Service, Southeastern Experiment Station, Ashville, NC.

U.S. Climate Date. 2015. *Climate Mississippi*. Available online at www.usclimatedate.com/climate/mississippi/united-states/3194; last accessed December 3, 2015.

USDA. 2005. *Potential timber damage due to Hurricane Katrina in Mississippi, Alabama and Louisiana*. Available online at http://www.srs.fs.usda.gov /katrina/katrina_brief_2005-09-22.pdf; last accessed July 18, 2014.

Web Soil Survey. 2015. Available online at http://websoilsurvey.sc.egov.usda.gov/App/HomePage.html/; last accessed July 22, 2015.

Williams, H. M. and Craft, M. N. 1998. First-year survival and growth of bareroot, container, and direct-seeded Nuttall oak planted on flood-prone agricultural fields P. 300-303 in Proc. of *ninth biennial southern silviculture research conference*, Waldrop, T.A. (ed.). USDA Forest Service, Southern Research Station, Asheville, NC.

Williams, H.M. and M. Stroupe. 2002. First-year survival and growth of bareroot and container water oak and willow oak seedlings grown at different levels of mineral nutrition. P. 338-341 in Proc. of *11th biennial southern silviculture research conference*, Outcalt, K.W. (ed.). USDA Forest Service, Southern Research Station, Asheville, NC.

Wilson, A.D. 2005. Recent advances in the control of oak wilt in the United States. *Plant Pathology. J.* 4(2):177-191.